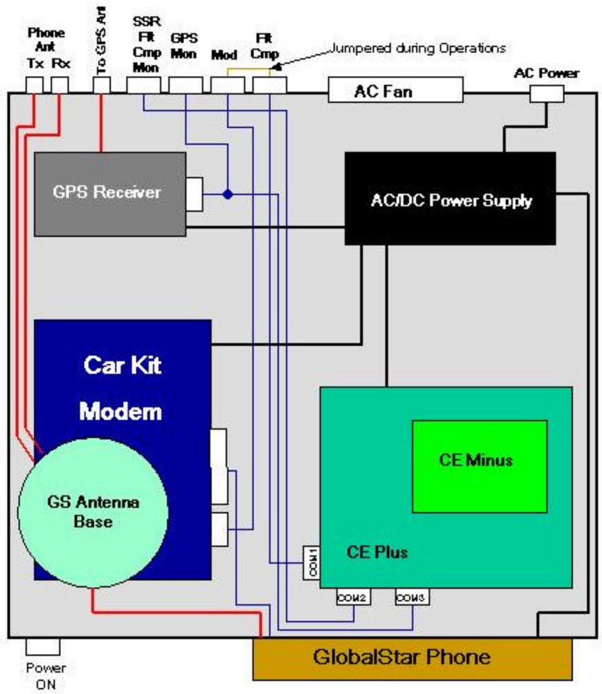
NASA Goddard Space Flight Center and the Wallops Flight Facility

Flight Modem Testing On the NASA P3 Aircraft



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June 2001

The NASA P3 aircraft at Wallops Flight Facility

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EXECUTIVE SUMMARY

The Flight Modem Demonstrates feasibility of 'launch vehicle as a node' for real time tracking using commercial satellite-based positional data without traditional ground and flight telemetry infrastructure. The flight modem uses COTS equipment capable of full duplex communications at 9600 baud to augment or replace low bandwidth telemetry tracking and control (TT&C) mission requirements. The Flight Modem can be combined with an on-board GPS receiver as a vehicle locator and effectively eliminate the need for down range radar tracking. Positional data can be relayed through a dial up socket connection to a known IP address at a central control station via a low earth orbiting (LEO) commercial satellite carrier.

The benefits of the Flight Modem are reduced ground station infrastructure, elimination of inherit scheduling conflicts, sustaining engineering, antenna equipment costs, reduced mission costs by an order of magnitude, drastic reduction in logistical issues, and worldwide access to low rate TT&C data.

This report documents the successful testing of the Flight Modem system aboard the NASA P3 aircraft at Wallops Flight Facility in May 2001. Flight Modem testing was conducted on two (2) flights and all operational characteristics of the system were tested and verified successfully. The ability of the system to remotely report accurate and real time positioning data in a conventional aircraft was confirmed as well as the ability to remotely control the in-flight modem via ground-initiated computer commands. Details of the processes, procedures and findings of the P3 test flights are detailed herein.

1.0 PURPOSE

In May 2001, the NASA P3 aircraft prepared to conduct an arctic mission to perform measurements on the Greenland ice field. The mission, named the Arctic Ice Measurement (AIM) project, was conducted during the mid-part of 2001. The flight modem was installed in the P3 as a piggy-back test during these preparation flights.

NASA is demonstrating the capability to monitor data in a real-time mode using remote equipment (commercial off the shelf, COTS, hardware & software) and satellite IP services. The advantage of such equipment, besides its obvious utility, is the extreme cost savings that can be realized when compared to traditional data-gathering systems and devices. The Flight Modem uses a relatively simple suite of components that can collect and format such data at the remote location, initiate a communications session over a commercial mobile satellite service (MSS) and transmit data over the communications link to a host computer at a centralized location.

In its initial testing, NASA is focusing on collecting and transmitting Global Positioning System (GPS) data for various types of aircraft. Globalstar is the current satellite commercial IP service provider that uses packet data service operating at 9600 bits-per-second. Data is sent from the on-board flight modem computer through the communications channel to a Globalstar satellite transponder, then to an earth station gateway where it is sent via the Internet to a terrestrial IP address of the host computer.

This report documents Flight Modem testing in conjunction with the P3 aircraft at Wallops Flight Facility (WFF). In particular, it discusses the preparation of the hardware and software relative to installation on the P3 as well as the findings of operations during two (2) test flights. The test flights were conducted on May 11, 2001 during an Engineering Check Flight (ECF) and on May 16, 2001 where it was piggy-backed on a flight sponsored by the University of Kansas for other test purposes relative to its primary mission.

1.1 Scope

The scope of this report is to document the processes, procedures and data analysis gathered relative to the Flight Modem and its use on test flights performed on board the P3 aircraft at the WFF.

1.2 Structure

This report contains the following sections:

1.0 Purpose and scope of the P3 Flight Modem Test
2.0 Reference documents relative to the Flight Modem

3.0 Flight Modem system components including details of the hardware, software and communications.
4.0 Test results detailing operational findings of the Flight Modem flight tests, data received and an analysis and critique of the data.
5.0 Finding and conclusion.

2.0 REFERENCE DOCUMENTS

(1) *CE-Minus, CE-Plus & LCD-Plus Hardware Manual*, Revision 2.00. RLC Enterprises Inc., November 2000.

(2) *QUALCOMM Globalstar GSP-1600 Tri-Mode Phone User Guide*, QUALCOMM Incorporated, 1999.

(3) *QUALCOMM Globalstar GSP-1620 Satellite Packet Data Modem Integrator's Reference Manual*, QUALCOMM Incorporated, 2000.

(4) *NASA WFF Flight Modem Web Page*, http://www.wff.nasa.gov/~fltmodm, 2001.

3.0 FLIGHT MODEM SYSTEM COMPONENTS

The basic components of the Flight Modem system include COTS hardware & software and a satellite IP communications link. Each component is detailed in the sections that follow.

3.1 Hardware

Hardware associated with the Flight Modem used on the P3 flights include the physical chassis and its peripheral equipment, the on-board computer, the packet data modem and phone assembly and a global positioning system (GPS) receiver and antennas for both the GPS and flight modem systems. Each of the components is discussed in the following paragraphs.

Note that the current Flight Modem is still in a prototype configuration necessary to test its functionality. Eventually, the design of the chassis will be streamlined to more efficiently use space and meet the particular demands of the environment in which it is implemented.

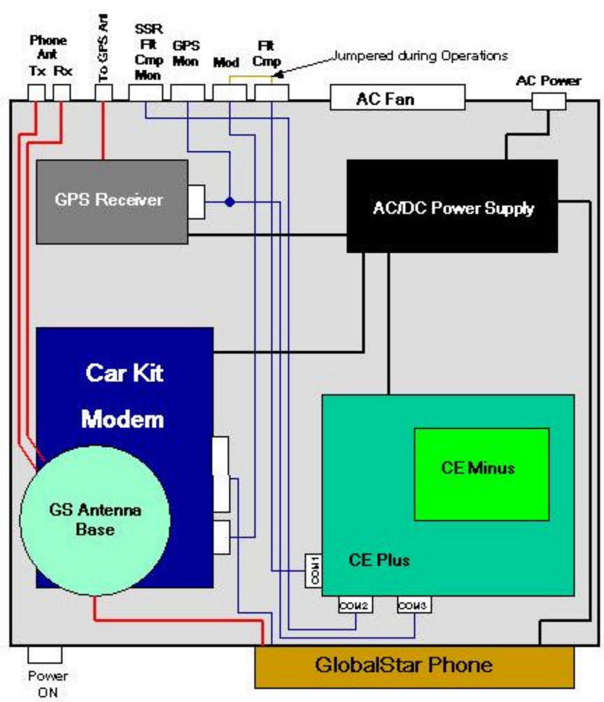


Figure 1 – Flight Modem Schematic

3.1.1 Chassis and Associated Equipment

The Flight Modem chassis consists of a fabricated metal box that is approximately four (4) rack units in height. It is designed to fit securely into a standard 19" equipment rack. *Figure 1* depicts a schematic of the chassis and its connections as used during the P3 flights.

3.1.2 Computer

The on-board computer for the Flight Modem system consists of two (2) components, the CE-Plus and CE-Minus, both supplied by RLC Enterprises, Inc. The CE-Plus primarily functions as an input/output (I/O) interface expansion board that allows for expanded connection of required power and data links.

The CE-Minus is a single-board computer providing the central processing unit (CPU), memory, clock, graphics and PCMCIA controllers, power management, keyboard interface and storage capabilities. The unit flown on the P3 included an AMD ELAN SC400 486 32-bit CPU operating at 100 MHz. Memory is provided by an 8 MB DRAM with the BIOS loaded on a separate 2 MB Flash EPROM. Storage is provided by a "disk-on-a-chip" functioning as an 8 MB hard drive.

During development, a miniature LCD screen (the LCD-Plus, also from RLC) was connected to the flight computer for ease of use. The screen was removed for the flight test to minimize weight and streamline functionality.

3.1.3 Phone and Modem Assembly

The phone/modem assembly in the Flight Modem chassis provides the communications channel necessary to transmit the on-board data to the remotely-located host. Globalstar provides the phone/modem and antenna system for use with its packet data and voice services. However, all these components are manufactured by Qualcomm.

The GSP-1620 packet data modem is the eventual preferred choice for use on the Flight Modem since it eliminates the requirement of having to deploy an actual voice handset, however, that unit was not available at the time of purchase in June 2000. Alternatively, the GSP-1600 phone and car-kit (with modem) was used and provided identical functionality.

The antenna used for the test was a modified version of Qualcomm's standard car-top antenna. The "standard" antenna consists of a base and antenna unit enclosed in a single plastic enclosure. The enclosure is outfitted with magnets for mounting on the roof of a car. The magnets were removed to reduce possible CPU performance and interference for the aircraft applications. The "base" section of the antenna provides some signal and power processing that is essential for operation of the system. The connection to the Qualcomm car-kit antenna enclosure is accomplished via a single SMA coaxial connector.

For this experiment, we required the use of an aircraft antenna (manufactured by ANTCOM Corp.) mounted on the outside top of the P3 fuselage. To accomplish this, we modified the "standard" Qualcomm car-kit antenna by disassembling the enclosure and separating the base from the antenna. Internal to the enclosure, the base connected to the antenna using two (2) RG-316U coaxial cables – one for signal transmit and one for receive. The cables were clipped and SMA connectors installed to their ends. The factory-provided antenna was then set aside for possible future use. The base unit was installed in the Flight Modem chassis and connected to SMA bulkhead connectors on the rear of the box. We then fabricated two 30-foot coaxial cables to connect the Tx/Rx plugs at the chassis to the same on the aircraft antenna on the P3.

3.1.4 GPS System

The GPS system includes a Synergy Systems GPS receiver and an antenna mounted on the top of the P3 fuselage. The GPS receiver electronics is manufactured by Motorola OnCore. This receiver is particularly well suited to high-altitude flights due to firmware which allows it operate over the export-controlled 60,000-foot ceiling. Synergy Systems is the vendor that supplies the OnCore in a box with convenient power, antenna and data connections and sells software with GUIs for convenient programming and real time data displays. Eventually, if we want to integrate a GPS receiver more closely with the flight modem, the actual OnCore board would be used, and not the Synergy Systems box. The system operates at L1 frequency with C/A code.

The antenna cable connection to the receiver was a standard BNC coaxial plug that was extended to another BNC plug mounted on the rear bulkhead of the chassis. A cable was then fabricated to cover the distance between where the chassis was mounted on the P3 and where the plug on the aircraft's GPS antenna was located. For this test, we used the existing GPS antenna on the P3 that required a standard N-type coaxial connector.

The GPS receiver was programmed to provide GPS data in a standard NMEA format at one sample per second of both GGA and GSV information (basic satellite and positional GPS data). The data was available via a serial port on the receiver that connected to the on-board computer by cable.

3.2 Software

System software was comprised of two primary components: the operating system of the on-board computer and the application software. Each of these is explained in the following sections in more detail.

3.2.1 Operating System

The operating system used for the on-board computer was Microsoft Windows CE, version 3.0. On the receiving computer (laptop), Microsoft Windows 98 SE was installed.

3.2.2 Application Software

The applications software is comprised of two (2) components: the flight computer software that is installed on the on-board computer and the "control" software that runs on the remote host computer.

The *flight computer software* was developed in the C++ computer language and performs the following functions:

1. Establishes a communications link to the Internet by "hand-shaking" and commanding the packet data modem to dial the Globalstar gateway.
2. Establishes a communications "pipe" to the host computer by opening a "socket" or port at the pre-determined IP address for connection by the host computer.
3. Handles hand-shaking with and parsing of data arriving from the GPS receiver.
4. Sets up log files to collect and store GPS data (GPSLOG.TXT) and system diagnostic data (SYSLOG.TXT).
5. Transmits GPS data (the GPSLOG.TXT file) to the host computer when the communication link is up and the socket connected.
6. Awaits commands from the host computer to perform the following functions:
    a. AUTO MODE: sets a flag to transmit data to the host computer only at predefined intervals and not on a continuous basis. For the P3 test, AUTO MODE, when used, was set to transmit for three minutes and "sleep" for three minutes in a continuous loop. AUTO MODE was developed to limit the "on-air" time of the phone to save costs where appropriate.
    b. HANG-UP: sends a command to the modem to hang-up the connection and not attempt a re-dial. The Flight Modem will NOT communicate again with the host computer unless the on-board computer is reset either by pressing the RESET button or by cycling the power on the chassis. HANG-UP mode was developed so that the modem could be deactivated in case of interference with other systems.
    c. CLEAR GPS FILE: this command effects the erasure of the GPSLOG.TXT file on the on-board computer's hard drive (disk-on-a-chip). This command was developed to permit the deletion of the file in the case of long duration testing where the size of the file itself neared the limit of the size of the hard drive. It also permits an easy way to initialize (e.g., zero-out) the file at the beginning of a mission.

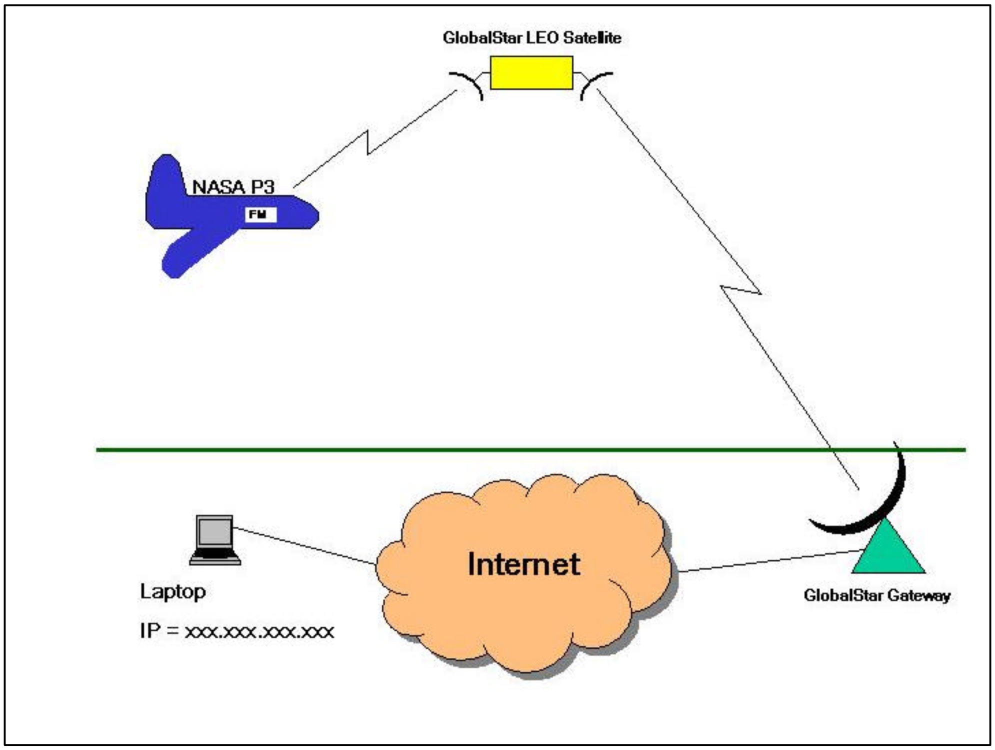
The *host control software* was developed in the C++ computer language and performs the following functions:

1. Provides the ability to initiate a connection by opening a socket to receive data coming from the flight computer at a static IP address.
2. Logs the received data on the local hard drive in a text file (GPSLOG.TXT)
3. Provides some elementary error detection by examining checksum information in the GPS data frames.
4. Provides a visual output of the incoming raw streaming data.
5. Provides a real-time, dynamic depiction of latitude, longitude and altitude as well as GPS time.
6. Provides the ability to initiate the AUTO MODE, HANG-UP and CLEAR GPS FILE commands.

3.3 Communications

The communications channel used during the P3 flight testing was provided by Globalstar's satellite packet data service. This service provides a synchronous data link operating at 9600 bits-per-second. Globalstar transmits in the frequency band between 1610 and 1625 MHz via commercial low-earth orbiting satellites (LEOS) orbiting at 1440 km above the surface of the earth. The signal is sent from the satellite transponder to a terrestrial earth station that provides a gateway into the Internet. Transmitter output power is regulated to between 0.4 and 2.0 W. The following illustration shows the components of the communications path for the Globalstar service and how it was used during the Flight modem test aboard the NASA P3.

TCP/IP communications protocols were used for this test. The host computer used the IP address 128.154.78.19 which is part of the network domain that includes the Telemetry Lab at WFF from where the testing was conducted.


GlobalStar LEO Satellite
NASA P3
FM
Internet
Laptop
IP = xxx.xxx.xxx.xxx
GlobalStar Gateway

4.0 TEST RESULTS

The Flight Modem was installed in the P3 near the bottom of a 19" rack situated about six (6) feet behind the bulkhead at the rear of the cockpit. A single cable was installed for the GPS receiver from the chassis to the GPS antenna located above and a little forward of the rack at the top of the fuselage. Total distance between the chassis and the GPS antenna was approximately 10 feet; however, the cable providing the connection was approximately 30 feet long (the excess was spooled at the bottom of the equipment rack). Two (2) cables (one transmit and one receive) were installed between the FM chassis and the ANTCOM antenna located above and 20 feet to the rear of the rack at the top of the P3 fuselage. Total distance from the chassis to this antenna was about 25 feet – each of the cables was approximately 30 feet in length. *Figure 2* below shows the flight modem chassis installed into the rack on the P3. *Figure 3* shows the location of the antennas on top of the fuselage.

Figure 2 – Rack in P3 with Flight Modem Chassis installed (bottom).

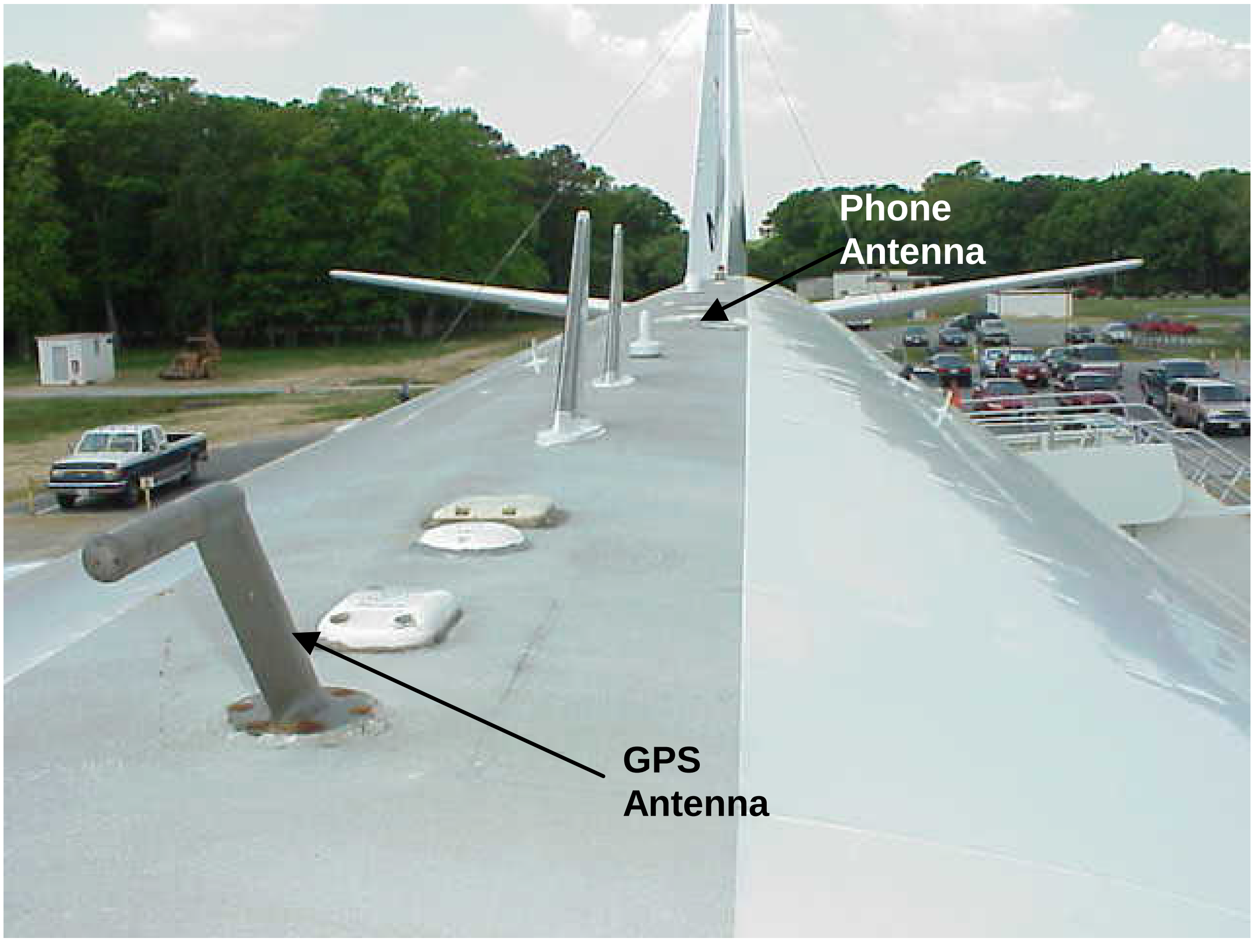


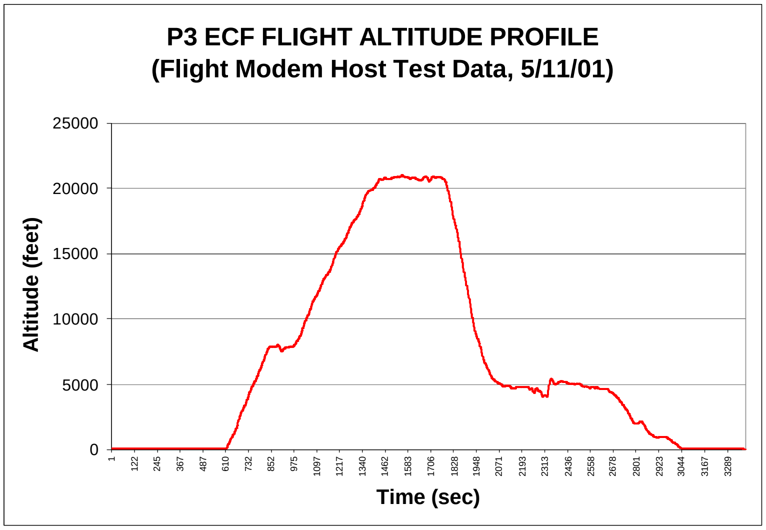
Figure 3 – Photo of the top of the P3 fuselage. The GPS antenna is closest in the foreground. The phone antenna is barely visible as the 8th antenna in line further to the rear.

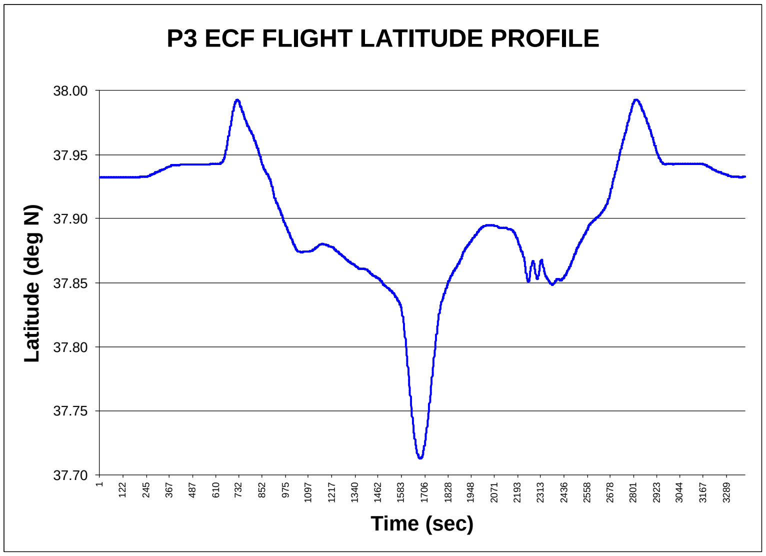
Testing was conducted during two (2) of the P3 flights. On May 11, 2001, the P3 underwent its Engineering Check Flight (ECF) where various operational systems were tested for flight-worthiness. The flight modem participated in the ECF. On May 16, 2001, the P3 flew a "Project Flight" devoted to experiments for the University of Kansas. The Flight Modem piggy-backed on this flight. Results of the two (2) test flights are summarized in the following sections, respectively.

4.1 P3 ECF Test

The Flight Modem electrical checkout flight (ECF) was performed on May 11, 2001. Prior to take-off, the power was applied to the flight modem and data was monitored throughout the flight until the modem was powered down after the P3 landed. None of the command elements of the system (AUTO MODE, HANG-UP, CLEAR GPS FILE) were tested during the ECF.

The ECF lasted a little longer than 40 minutes with take-off occurring at 10:04:24 AM EDT and landing at 10:45:05 AM EDT. Data was collected on the ground by the receiving laptop for a total of 1:01:40 from 9:54:14 to 10:55:54 EDT. The Flight Modem system worked exactly as planned during the entire duration of the test. No errors occurred in the collection of the GPS data and satellite lock was not lost during the entire flight. A total of 3,384 frames of data were collected for positioning information (GPS GGA data) and provided profiles of the P3 flight with respect to altitude, latitude and longitude in the three (3) charts that follow, respectively. Note that elapsed time of the test is depicted on the X-axis of each of the following charts.





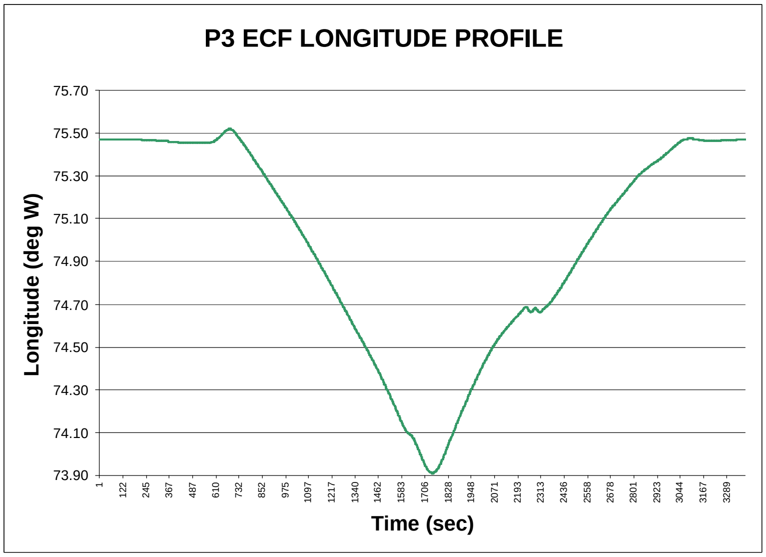


Figure 4 –Altitude, Latitude, Longitude Profiles over time of the Electrical Checkout Flight (ECF), 05/11/2001

4.2 P3 Project Flight Test

The Flight Modem was tested again for basic operations including the command elements of the system (AUTO MODE, HANG-UP, CLEAR GPS FILE) on May 16, 2001. Prior to take-off, the power was applied to the flight modem and data was monitored for an initial period. (WHAT WAS THE PERIOD OF TIME?) The modem was then commanded from the ground to execute AUTO MODE operations with a cycle of three (3) minutes of transmit and three (3) minutes of "sleep" time. AUTO MODE was toggled off before landing. After landing, the modem was commanded to HANG-UP, thus completing the operational phase of the test.

The Project Flight test duration was 1:50:24 with take-off occurring at 8:18:29 AM EDT and landing at 10:08:53 AM EDT. Data was collected on the ground by the receiving laptop for 2:02:39. Start and stop data collecting times were from 8:06:45 to 10:09:24 EDT. Data on the Flight Modem computer was collected for a total of 2:08:54 from 8:05:38 to 10:14:32 EDT. NOTE: the FM computer collected continuous data from the time it was turned on in the P3 until it was powered down after the flight where the host computer collected only a SUBSET of that data that was transmitted during the time the communications link was up. That is, no data was collected on the host laptop before the LISTEN FOR CONNECTION command was activated, during the AUTO MODE sleep time or after the HANG-UP command was issued. A table chronology of events follows:

EDT	**EVENT**
08:05:38	Power on to FM chassis and phone, begin FM data collection

08:06:45	Initiated socket connection on host, begin host data collection
08:18:29	P3 airborne
08:21:40	AUTO MODE command initiated by host
08:24:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:27:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:27:53	Socket reconnects, data collection restored at host
08:30:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:33:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:33:51	Socket reconnects, data collection restored at host
08:36:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:39:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:39:51	Socket reconnects, data collection restored at host
08:42:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:45:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:45:55	Socket reconnects, data collection restored at host
08:48:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:51:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:51:51	Socket reconnects, data collection restored at host
08:54:40	3 minutes elapsed, host goes to “sleep” for 3 min.
08:57:40	3 minutes elapsed, host listens after coming out of “sleep” mode
08:57:51	Socket reconnects, data collection restored at host
09:00:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:03:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:03:51	Socket reconnects, data collection restored at host
09:06:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:09:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:09:51	Socket reconnects, data collection restored at host
09:12:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:15:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:15:53	Socket reconnects, data collection restored at host
09:18:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:21:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:21:53	Socket reconnects, data collection restored at host
09:24:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:27:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:27:52	Socket reconnects, data collection restored at host
09:30:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:33:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:33:51	Socket reconnects, data collection restored at host
09:36:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:39:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:39:51	Socket reconnects, data collection restored at host
09:42:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:45:40	3 minutes elapsed, host listens after coming out of “sleep” mode
09:45:53	Socket reconnects, data collection restored at host
09:48:40	3 minutes elapsed, host goes to “sleep” for 3 min.
09:51:40	3 minutes elapsed, host listens after coming out of “sleep” mode

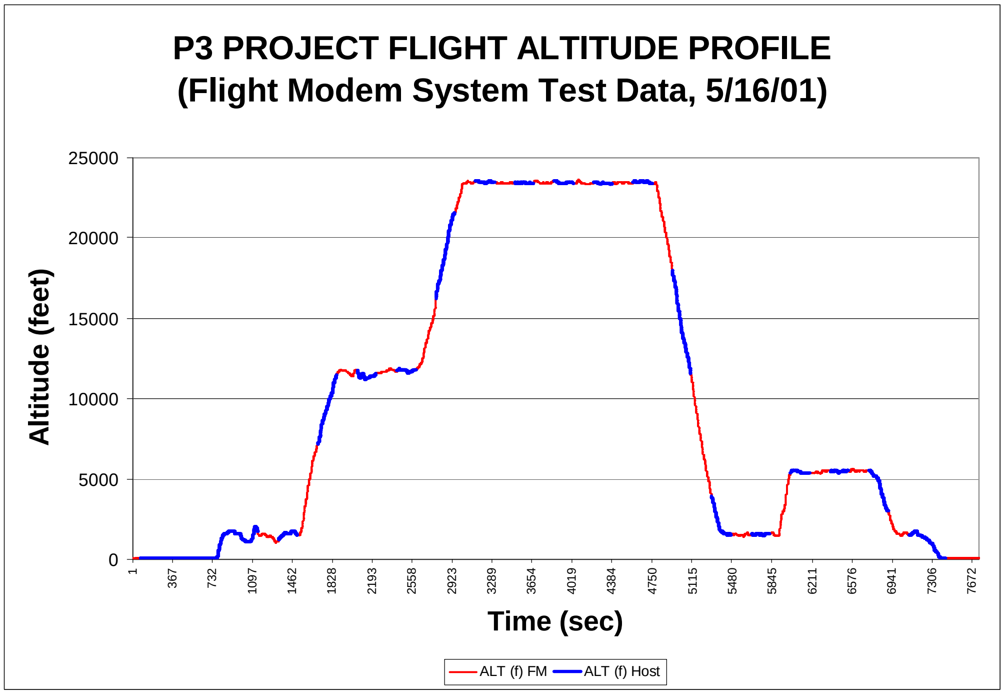
09:51:55	Socket reconnects, data collection restored at host
09:54:40	3 minutes elapsed, host goes to "sleep" for 3 min.
09:57:40	3 minutes elapsed, host listens after coming out of "sleep" mode
09:57:51	Socket reconnects, data collection restored at host
10:00:40	3 minutes elapsed, host goes to "sleep" for 3 min.
10:03:40	3 minutes elapsed, host listens after coming out of "sleep" mode
10:03:51	Socket reconnects, data collection restored at host
10:04:21	AUTO MODE toggled "off" at host
10:08:53	P3 landed
10:09:24	Host initiated HANG-UP command, data collection halted at host
10:14:32	Power off to FM chassis, data collection halted at FM, test complete

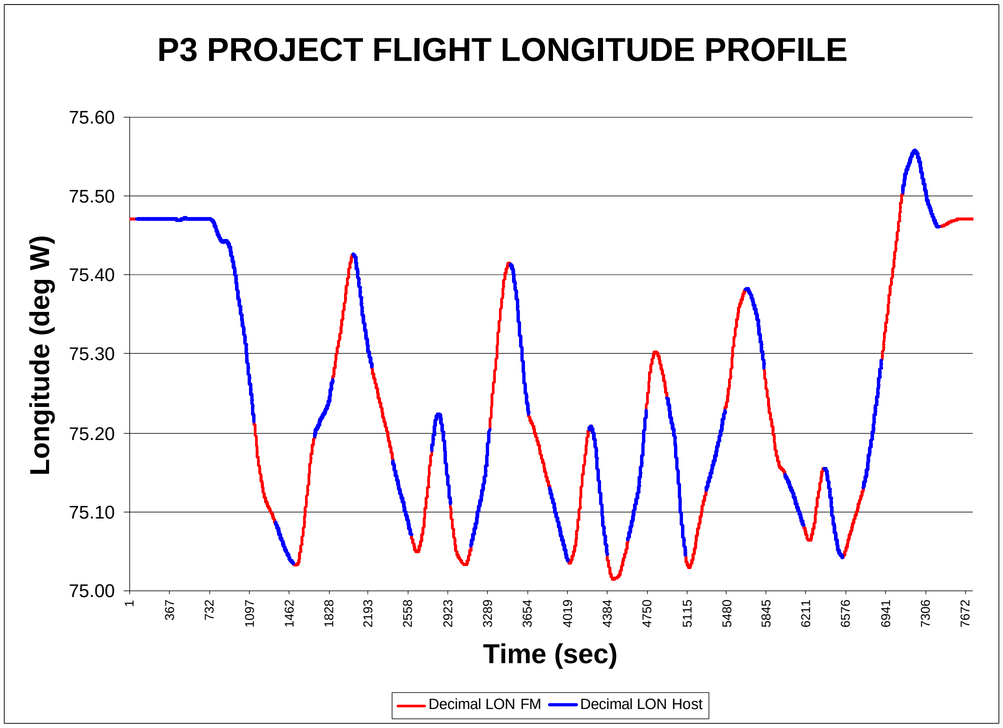
From the above, please note that there were seventeen (17) 6-minute ON/OFF cycles of the AUTO MODE feature. Also note that there was a lag of time from the moment AUTO MODE came out of "sleep" to when the connection was re-established. This is due to the dialing and hand shaking required to make a new connection. During the 17 cycles, this lag time varied between 11 and 15 seconds with an average of 11.12 seconds.

Overall, the Flight Modem system worked exactly as planned during the entire duration of the test. No errors occurred in the collection of the GPS data and satellite lock was not lost during the entire flight. A total of 7,734 frames of data were collected for positioning information (GPS GGA data) on the FM computer and provided profiles of the P3 flight with respect to altitude, latitude and longitude respectively as depicted in the three (3) charts that follow. Note that these figures include BOTH the FM data and the host computer data for comparison and to graphically illustrate the effective operations of the AUTO MODE and HANG-UP commands.

4.3 EMI/RFI

During both flights, the ECF and Project flights, there were no reported electromagnetic or other radio frequency interference (EMI/RFI) problems caused by the flight modem transmitter to any instrumentation system on the P3. Similarly, the aircraft instrumentation did not interfere with the operations of the Flight Modem.


P3 PROJECT FLIGHT ALTITUDE PROFILE
(Flight Modem System Test Data, 5/16/01)
Altitude (feet)
25000
20000
15000
10000
5000
0
1
367
732
1097
1462
1828
2193
2558
2923
3289
3654
4019
4384
4750
5115
5480
5845
6211
6576
6941
7306
7672
Time (sec)
ALT (f) FM
ALT (f) Host


P3 PROJECT FLIGHT LONGITUDE PROFILE
Longitude (deg W)
75.60
75.50
75.40
75.30
75.20
75.10
75.00
1
367
732
1097
1462
1828
2193
2558
2923
3289
3654
4019
4384
4750
5115
5480
5845
6211
6576
6941
7306
7672
Time (sec)
Decimal LON FM
Decimal LON Host

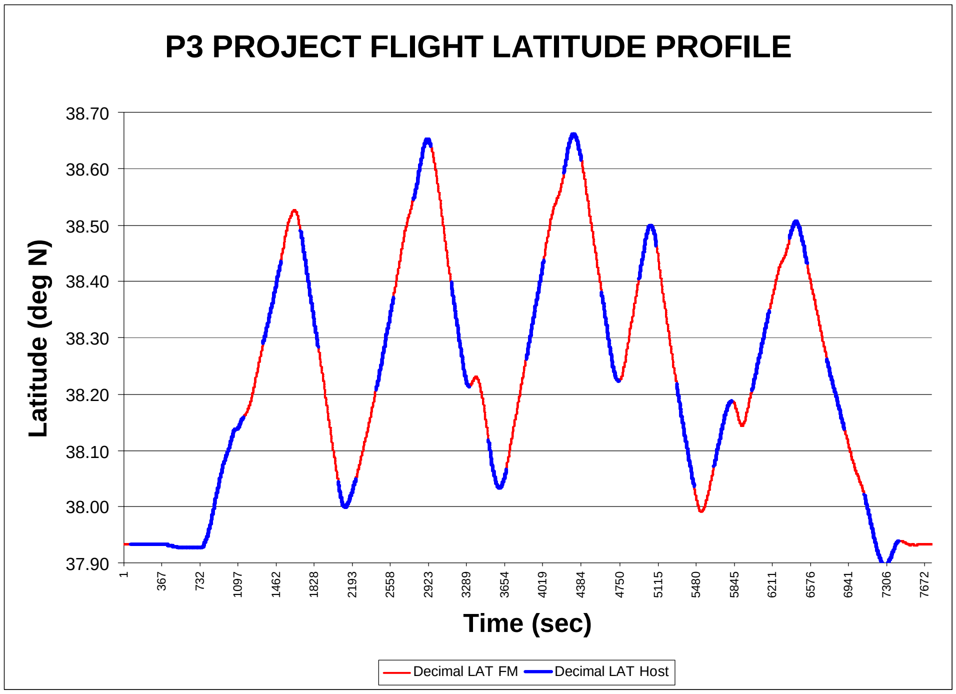


Figure 5 –Altitude, Longitude, and Latitude Profiles over time of the P3 Project Flight test, 05/16/2001

5.0 FINDINGS AND CONCLUSION

This report has presented information relative to the NASA Flight Modem system and its subsequent testing aboard the NASA P3 aircraft. Various components of the system were discussed with details presented on hardware, software and communications. The Flight Modem tests conducted included GPS data flows using over the horizon IP satellite communications, on-board computer logging, and near real-time terrestrial terminal logging via the Globalstar satellite constellation. All Flight Modem systems function performed nominally and did not cause any interruption in data streaming or RF interference with other on board instruments.